

Gamification Improves Neurofeedback Performance and Experience among Users with ADHD: Findings from NeuroWizard II

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ABSTRACT: This study explored the effect of gamification on neurofeedback (NF) training in individuals with Attention-Deficit/Hyperactivity Disorder (ADHD). In a within-subjects design, 16 participants with ADHD completed both a gamified and a non-gamified NF task delivered via a Brain-Computer Interface (BCI). Task performance and user experience were evaluated across conditions. The gamified condition led to a higher task accuracy and better user experience, characterized by greater immersion and lower negative affect. However, some participants also reported increased mental fatigue. Notably, most participants expressed a preference for the gamified version, describing it as more motivating and engaging. These findings suggest that carefully applied gamification can enhance both the effectiveness and enjoyment of NF training for individuals with ADHD, paving the way for the development of more user-centered therapeutic tools.

INTRODUCTION

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of our modern society's most prevalent neurodevelopmental disorders, causing approximately 8-12% of the children worldwide to struggle with impulsive and disorganized behavior, physical and mental restlessness, and difficulties to keep focused attention [1]. Those behavioral symptoms relate to distinct neurophysiological characteristics such as elevated theta and reduced alpha and beta activity in the electroencephalographic (EEG) profiles of individuals with ADHD [2, 3] and can persist into adulthood for up to 65% of the diagnosed children [1]. ADHD can thereby not only impact the individual's education, professional career, and personal relationships but also increases their vulnerability to other psychiatric conditions and comorbidities like depression, anxiety, or bipolar disorder and substance abuse [4]. Though currently not curable, a range of therapeutic interventions have been shown to improve symptoms of ADHD and the quality of life of affected individuals [1]. Alongside medication-based interventions, non-pharmacological treatment options for example using neurofeedback (NF) delivered via a Brain-Computer Interface (BCI) have gained popularity in more recent times, to evade the drawbacks of a continuous use of med-

ication [5, 6].

During NF training, the user learns to actively regulate their brain activity through a variety of different mental strategies, for which they receive real-time feedback from a closed-loop BCI system [7]. However, given that attention, concentration, and motivation can influence BCI task performance [8], a significant limitation of standard NF and BCI training protocols lies in their reliance on repetitive and monotonous tasks; a flaw in protocol design that is thought to be partially responsible for BCI inefficiency [9]. BCI inefficiency describes the phenomenon whereby 15-30% of users are unable to successfully control a BCI [10], a problem that is crucially linked to the success of NF training as a treatment method [11, 12]. To address this issue, several studies within the broader BCI literature have proposed the use of gamification as a strategy to enhance user motivation and engagement during training [13]. Gamification refers to the integration of game design elements into non-game contexts to foster increased user participation and intrinsic motivation [14]. A recent systematic review identified 14 commonly used game elements in motor imagery-based BCI training systems and found evidence that gamification generally improves user experience and BCI training outcomes [15].

However, most of the current evidence on the impact of gamification in NF training is based on studies involving healthy individuals. Another recent systematic review [16] highlighted the limited and inconsistent research specifically investigating the effect of gamified NF training in populations with ADHD. While some studies suggest that gamification may enhance motivation and engagement in individuals with ADHD [17], others caution that gamified elements may introduce distractions or lead to frustration [5, 18, 19]. Importantly, out of the 219 studies screened by Kohnen et al. [16], only 14 empirical studies specifically examined gamified BCI applications for NF training in individuals with ADHD. Many of the excluded studies failed to validate their systems with formally diagnosed participants, thus violating the principles of user-centered design essential for the development of effective BCI systems [20].

Therefore, the state-of-the-art literature does not provide

reliable conclusions or guidelines for developing NF applications that offer users with ADHD an optimal experience while improving their performance [16]. The heterogeneity in game design and outcome measures used, alongside the definite lack of studies directly comparing gamified to non-gamified approaches, highlights a critical gap in the literature. To address this gap, the current study sought to explore whether, and how, gamification should be applied to standard NF systems used by individuals with ADHD. We aimed to generate empirical insights that could inform the design of more effective and user-centered NF applications tailored to this target population.

Building on the work of Vrins et al. [17], we developed *NeuroWizard II*, a NF game designed to support attention training in individuals with ADHD using a time-modulated visually evoked potential (tVEP) BCI¹. Compared to the earlier version presented in Vrins et al. [17], *NeuroWizard II* emphasizes a more immersive form of gamification beyond surface-level elements, by embedding visual feedback directly into the game environment, incorporating a more elaborate narrative, minimizing distractions, and eliminating calibration interruptions between BCI blocks. To evaluate the effect of gamification, we compared *NeuroWizard II* to a non-gamified version of the same BCI task. Data was collected from 16 individuals formally diagnosed with ADHD, focusing on user experience, user preference, and task performance. Our research questions were formulated as follows:

- RQ1: *Does gamification of NF training improve BCI task accuracy for users with ADHD?*
 RQ2: *Does gamification of NF training improve interaction experience for users with ADHD?*
 RQ3: *Which one do users with ADHD prefer: A gamified NF training application or a non-gamified standard version of the same training?*

Based on the existing literature [15, 17], we hypothesized that both the BCI task performance and user experience would be better in the *NeuroWizard II* game compared to the standard non-gamified task and that the game would be preferred by most users.

BCI SYSTEM DEVELOPMENT

tVEP Protocol: Both versions of the NF task were developed using the Unity game engine version 6000.0.37.f1 [22] in combination with the eight-channel Unicorn Hybrid Black EEG headset (g.tec Medical Engineering, Austria). The Unicorn Hybrid Black provides an integrated Unity plugin for BCI game development with a complete pipeline for EEG-signal preprocessing and clas-

¹Note that the application developed here is referred to as a NF application following Fouillen et al. [21], though it is not a NF application in the traditional sense [7] and might also be described as a BCI-based attention-training task with NF-like feedback from a closed-loop EEG setup. Importantly, the present study is of a strictly design-focused nature and does not aim to validate a tVEP based paradigm as a self-regulation strategy or investigate the intervention's impact on ADHD symptoms.

sification, enabling the creation of immersive 2D or 3D environments controlled by EEG signals. In the present study, a tVEP-based BCI was implemented to translate neural responses into in-game commands.

While traditionally NF applications for users with ADHD rely on the targeted modulation of endogenous brain signals like sensorimotor rhythms (SMR), slow cortical potentials (SCP) or theta-beta ratios (TBR) [23], we decided to use a VEP-based design. VEPs are directly elicited by visual attention, which could make the BCI more intuitive to control while reducing ambiguity in signal interpretation [16, 21].

Game Design in Unity: Participants played as a wizarding apprentice completing a final challenge to join the council. The game comprised three BCI-based quests (see Fig. 1 for design example), themed by seasons: brewing a mushroom potion (autumn), navigating a forest via light-guided paths (winter), and fighting demons (summer). Cut-scenes between BCI blocks introduced in-game characters and objectives and advanced the narrative. Each BCI block included eight four-class selections, with up to three attempts per target guided by scene-specific cues. Target positions were pseudo-randomized, ensuring that no item appeared in the same location in consecutive selections, thereby preventing accidental double selections.

With this design, creating game-immersed visual feedback entailed the incorporation of the game elements *narrative*, *reward* (one collectible item per quest), *score* (implicitly through a progress bar for each scene), and *feedback* (see a full list of game elements commonly applied to BCIs in [15]). While feedback is inherent to NF systems, it was explicitly gamified by embedding the VEP stimuli seamlessly into the game environment and providing visual feedback through environmental changes that reflected user performance. Explicit visual feedback was provided through green or red colored rings appearing around the VEP stimuli that the user had to focus on, indicating correct or incorrect selections. Game elements were chosen to enhance motivation and engagement while minimizing the risk of distraction or stress. Hence, other commonly used elements such as *levels* or *timers* were deliberately excluded [15, 16].



Figure 1: Block 3 of the Gamified Task: Summer-Themed quest

Standard BCI Task: The standard BCI condition was

designed to closely mirror the structure of the gamified task while omitting the immersive game elements. As in the gamified task, the standard task included three BCI blocks, each requiring participants to complete eight four-class selections, with up to three attempts allowed per selection. However, unlike the immersive design of the gamified version, stimuli here were displayed as four black circles flashing on a plain blue background using the same design for all three BCI blocks (see Figure 2). Target items were indicated by a red arrow above the target VEP stimulus. The target item order was again pseudo-randomized, with precautions implemented to prevent double selections. Between the three BCI blocks, short instructional texts were presented to guide participants through the task. No progress bar or reward system was included. The only feedback came from colored rings around the stimuli, with green rings indicating correct selections and red marking incorrect ones. Overall, both conditions used identical BCI mechanisms, differing only in presentation: the gamified version embedded the task in a narrative-based interactive game environment, whereas the standard version used a minimalistic interface. Videos showcasing both tasks can be found alongside the code for development and analysis at <https://github.com/khnhenriette/NFforADHD>.

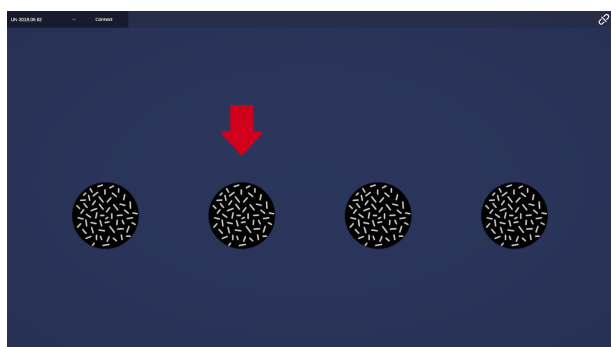


Figure 2: Design of the Standard Task

VALIDATION STUDY

Participants: The study included 17 participants living in the Netherlands or Germany with a formal ADHD diagnosis by a licensed professional. One participant was discarded due to technical issues. The final sample consisted of 16 participants between 19 and 40 years of age ($M = 25.8$; $SD = 6.2$). Nine participants self-identified as male, six as female, and one as non-binary. The study was approved by the ethics committee of Tilburg University's School of Humanities and Digital Sciences and received ethical clearance under the identification code REDC 2024.07a.

Procedure: We used a within-subjects design with randomized condition order to control for novelty, learning, and exhaustion effects. The whole experiment lasted around 60 minutes and took place in a soundproofed room, where participants were seated approximately 50

cm away from a screen adjusted to eye level. After providing informed consent and completing a pre-questionnaire, participants were fitted with an EEG cap and completed both the gamified and non-gamified BCI conditions in randomized order. Following each condition, they filled out the Game Experience Questionnaire (GEQ) [24]. After completing both conditions, participants indicated their preferred condition, provided a brief justification, and were debriefed.

Measures: BCI task accuracy was computed as the proportion of correctly selected items out of total selections, resulting in six accuracy measures across three BCI blocks in two conditions, as well as overall accuracy per condition. Differences between conditions were analyzed at both the aggregate and block level to assess potential learning or exhaustion effects. User experience was assessed using the Core and Post-game modules of the GEQ, with subscales aggregated according to Ijsselstein et al. [24]. Preference data was collected via a multiple choice selection indicating a preference for the gamified, non-gamified, both or neither conditions and open-text justifications.

Data Analysis: A Bayesian 2x3 repeated measures ANOVA was run on the factors *condition* and *block number* to investigate the possible differences in BCI task accuracy between the conditions. For all statistical tests, it was made sure the respective assumptions were met using Q-Q plots and the Shapiro-Wilk test [25]. For the analysis of the GEQ data, a Bayesian paired t-test was run, if the component-wise differences between the conditions met the normality assumptions. If not, a Bayesian Wilcoxon signed-rank test was used instead. The subjective preference indications were analyzed using a Bayesian Multinomial test, while the justifications were simply considered as supporting data and to provide guidelines for possible future research directions.

Bayesian Hypothesis Testing: Instead of traditional frequentist tests, such as t-tests or ANOVAs with p-values, this study employed their Bayesian equivalents. Bayesian hypothesis testing is based on the Bayes Factor (BF), which quantifies the relative evidence for the alternative versus the null hypothesis and allows for graded evidence rather than binary decisions [26, 27]. A BF of 1 indicates no evidence for either hypothesis, values greater than 1 favor the alternative hypothesis, whereas values below 1 favor the null hypothesis, with larger deviations from 1 reflecting stronger evidence [27].

RESULTS

BCI Task Accuracy: BCI task performance was consistently above chance level with the per-block accuracies ranging between 42.86% and 100% ($M = 74.76$; $SD = 16.25$) for the gamified condition and between 33.33% and 100% ($M = 65.85$; $SD = 13.82$) for the standard condition. The overall BCI accuracy was higher in the gamified condition than in the standard condition. The Bayesian repeated measures ANOVA (Table 1) revealed

strong evidence for an effect of condition ($BF = 16.11$), and very strong evidence for a block and condition interaction ($BF = 70.91$), while there was no main effect of BCI block number alone ($BF = 0.87$).

Table 1: Results of the Bayesian 2x3 repeated measures ANOVA examining the differences in BCI accuracy between conditions and BCI blocks. Strong evidences are indicated in bold.

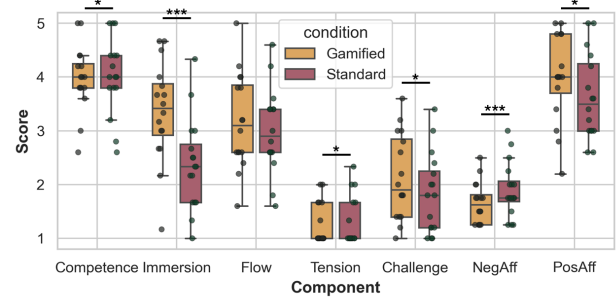
Models	BF
block	0.87
condition	16.11
block + condition	17.90
block + condition + block:condition	70.91

Post-hoc Bayesian paired t-tests (Table 2) indicated no strong evidence for a difference between conditions in block 1 ($BF = 0.28$). However, there was very strong evidence for higher accuracies in the gamified condition in block 2 ($BF = 38.19$) and moderate evidence for higher accuracies in the gamified condition in block 3 ($BF = 3.57$). Within the gamified condition, moderate evidence was found for higher accuracies in block 2 ($BF = 5.72$) and block 3 ($BF = 4.98$) compared to block 1, while no difference was found between blocks 2 and 3. In contrast, no block differences were observed within the standard condition.

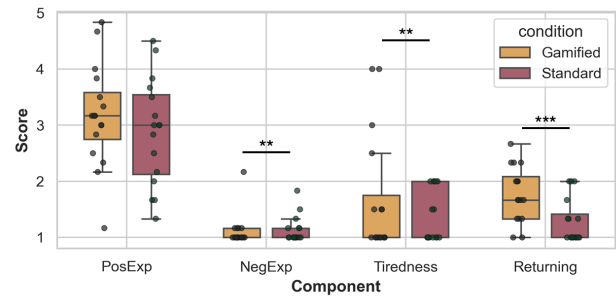
Table 2: Results of the post-hoc Bayesian paired t-tests comparing accuracies between conditions and BCI blocks. Strong and moderate evidences are indicated in bold.

Post-hoc comparisons	Relationship tested	BF
between conditions	gamified 1 > standard 1	0.28
	gamified 2 > standard 2	38.19
	gamified 3 > standard 3	3.57
between block numbers	gamified 1 < gamified 2	5.72
	gamified 1 < gamified 3	4.98
	gamified 2 < gamified 3	0.33
	standard 1 < standard 2	0.26
	standard 1 < standard 3	0.35
	standard 2 < standard 3	0.32

Game Experience Questionnaire: The GEQ Core module (Figure 3a) showed extreme evidence for higher immersion in the gamified condition ($BF = 331.27$) and strong evidence for higher negative affect in the standard condition ($BF = 23.03$). All other Core module components showed only anecdotal evidence: challenge ($BF = 1.56$) and positive affect ($BF = 1.74$) were rated slightly higher in the gamified condition, competence ($BF = 1.42$) and tension/annoyance ($BF = 1.70$) were slightly higher in the standard condition, and flow ratings showed no difference ($BF = 0.44$). In the Post-game module (Figure 3b), positive experience showed no evidence in favor of either the null or the alternative model ($BF = 1.01$). Negative experience was higher in the standard condition ($BF = 3.41$), and tiredness ($BF = 8.20$) and returning to reality ($BF = 30.37$) were higher in the gamified condition, with



(a) Core Module of GEQ



(b) Post-Game Module of GEQ

Figure 3: Boxplots of GEQ responses for each condition, overlaid with individual data points. * BF Indicates Anecdotal Evidence for a Difference. ** BF Indicates Moderate Evidence for a Difference. *** BF Indicates Strong Evidence for a Difference.

moderate and strong evidence, respectively.

Subjective User Preference: Participants showed an overwhelming preference for the gamified BCI task ($BF = 18,469.21$). 14 participants (88%) favored it, while one preferred the non-gamified version and one liked both equally. Participants frequently reported the storyline and visuals to increase enjoyment, engagement, motivation, and provide a sense of accomplishment. Opinions were mixed regarding which version better supported focus, and some participants described higher pressure or additional workload in the gamified condition.

DISCUSSION

The aim of this study was to investigate the effect of gamification on BCI-based NF training for individuals with ADHD. Although numerous NF games have been developed, they are most often validated in healthy populations, leaving their efficacy in individuals with ADHD largely unexplored [16]. This study hypothesized that gamification would enhance both BCI task performance and user experience, and that a gamified NF training application would be preferred over a standard one by the majority of participants in this cohort. The results support this hypothesis; BCI task accuracy was higher in the gamified than in the standard condition. The Bayesian ANOVA showed strong evidence for an effect of con-

dition, with post-hoc tests indicating higher accuracy in the gamified condition, particularly in blocks 2 and 3 following repeated task exposure. Prior research has reported mixed effects of gamification on BCI task performance [15, 17–19], likely depending on the specific implementation and the presence of additional in-game distractions. In the present study, the gamified BCI application was carefully designed to avoid unnecessary distractions for the participants, and the results suggest that thoughtfully implemented gamification can indeed enhance BCI task performance. Notably, the very strong block-condition interaction indicates that the benefits of gamification emerge over time, particularly as users' motivation or engagement with the task naturally declines. Within the gamified condition, BCI accuracy was higher in blocks 2 and 3 than in block 1, whereas no such progressions were observed in the standard condition. This pattern could reflect increased engagement, motivation, or learning in the gamified task, potentially counteracting detrimental effects of boredom and mind-wandering that can arise in later stages of BCI training, which is typical among individuals with ADHD [5]. Overall, these findings align with prior work highlighting motivation as a key psychological factor for BCI performance [8].

The results of the two GEQ modules were also in line with the hypothesis and largely replicate prior findings [17]. The results of the Core module mostly replicate previous trends, showing higher immersion and lower negative affect in the gamified BCI application. Compared to the older version of the *NeuroWizard* game reported by Vrins et al. [17], the current study provided stronger evidence for increased immersion and reduced negative affect in the gamified condition. In contrast, challenge showed anecdotal evidence in the opposite direction, with slightly higher values in the gamified condition, which might reflect increased perceived cognitive demand in gamified tasks [19]. Additionally, small anecdotal effects for lower perceived competence in the gamified condition were observed in the present study, which may similarly reflect slightly higher perceived difficulty in the gamified task, even though the tension/annoyance ratings were lower than in the standard condition. Given the careful gamification design including scores and rewards, but no timer or levels, it is unsurprising that evidence for tension, challenge, and competence remained overall weak. The strong increase in immersion suggests the BCI task was successfully integrated into a coherent game experience, improving interest and experiential richness consistent with the narrative-driven design [24]. Conversely, higher negative affect in the standard condition reflects higher levels of boredom, monotony, and mind-wandering as captured by the GEQ items [24], and aligns with the lower BCI accuracy observed for the standard task [5].

As no prior work has reported Post-game GEQ results within the same context, direct comparisons are not possible. Nevertheless, the higher negative experience in the standard condition is consistent with the results of

the Core module. Further, greater immersion would make disengagement harder [13, 19], possibly explaining higher difficulty in returning to reality. Higher tiredness in the gamified condition is also in line with previous studies suggesting gamified tasks can feel more demanding [19]. Task duration likely contributed as well, since the gamified version took longer to complete due to narrative cut-scenes, despite identical underlying NF components. Overall, the results of the two GEQ modules could be taken together to suggest a better user experience for the gamified version of the NF training. The components showing higher values for the gamified condition are mostly related to a better experience (e.g., immersion, positive affect), while the components exhibiting higher values for the standard condition are pointing towards a slightly worse experience (e.g., tension, negative affect, negative experience).

In BCI research, subjective experience does not always reflect task performance, although correlations can occur [28, 29]. In the present study, GEQ ratings broadly aligned with BCI accuracy, and individual preferences showed some similar patterns. Interestingly, the participant who preferred the standard condition also demonstrated higher accuracy in that condition, whereas the participant who reported equal preference for both conditions showed one of the smallest accuracy differences between the two conditions. In conclusion, the findings of this study suggest that careful gamification of NF training tasks can improve user experience and not only preserve but also enhance BCI task performance among individuals with ADHD, offering valuable design guidance for the development of future gamified NF applications.

Limitations and Future Work: A primary limitation of this study is the small, demographically restricted sample ($n = 16$), consisting mainly of university students. Although slightly larger than samples in prior work [17], it is not representative of the heterogeneous ADHD population [1], limiting generalisability. Future studies should recruit larger, more diverse samples and examine the influence of factors such as age, gender, BCI experience, medication, and gaming background. Second, the gamified scenes were presented in a fixed order, wherefore observed effects may in parts reflect scene-specific design characteristics (e.g., intuitiveness or target detectability). Randomizing game scene order would help control for such potential confounds. Third, multiple game elements were combined in the current design, making it difficult to determine which features contributed to performance improvements and which may have introduced distraction. Future work should systematically vary individual game elements while maintaining a user-centered, low-distraction design to optimize BCI performance and user experience.

Beyond this paradigm, alternative VEP-based BCI approaches such as Steady-State VEPs or code-modulated VEPs, could enable more flexible designs with more classes [30]. It would also be valuable to compare gamified and non-gamified versions of established NF proto-

cols (SCP, SMR, TBR) which not only avoid visual fatigue associated with prolonged use of VEP-based BCIs [31], but importantly, have already demonstrated clinical efficacy for ADHD [23]. Nevertheless, the simplicity and inherent reliance on user attention make visual stimuli a compelling option for future applications. As this study is strictly exploratory and design-focused, longitudinal follow-up studies should investigate the impact of VEP-based training-applications like *NeuroWizard II* on ADHD symptoms. Finally, different game themes should be explored, as user preferences varied even within this small sample, highlighting the importance of adaptable, user-centered design.

CONCLUSION

This study addresses a critical research gap in designing NF training applications for individuals with ADHD, with potential implications for therapeutic interventions. The findings show that carefully implemented gamification can enhance both BCI task performance and user experience, and that most participants prefer a gamified over a non-gamified version. Importantly, these effects were supported by both subjective measures (GEQ and user preferences) and objective accuracy metrics. Together with the identified limitations and proposed directions, the results provide valuable guidance for optimizing therapeutic NF interventions for ADHD. Moreover, the gamified application developed in this study, which is openly available on GitHub, offers a foundation for further development and evaluation of engaging, effective NF training games.

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